Journal of Cardiology (2011) **58**, 294—299

ScienceDirect

journal homepage: www.elsevier.com/locate/jjcc

JOURNAL of CARDIOLOGY

Original article

Impact of 64 multi-detector computed tomography for the evaluation of aortic paraprosthetic regurgitation

Masahiko Hara (MD)[a,*], Masami Nishino (MD, PhD, FJCC)[a], Masayuki Taniike (MD, PhD)[a], Nobuhiko Makino (MD, PhD)[a], Hiroyasu Kato (MD)[a], Yasuyuki Egami (MD)[a], Ryu Shutta (MD)[a], Jun Tanouchi (MD, PhD, FJCC)[a], Toshihiro Hunatsu (MD, PhD)[b], Kazuhiro Taniguchi (MD, PhD)[b], Yoshio Yamada (MD, PhD, FJCC)[a]

[a] *Division of Cardiology, Osaka Rosai Hospital, Sakai, Osaka, Japan*
[b] *Department of Cardiovascular Surgery, Osaka Rosai Hospital, Sakai, Osaka, Japan*

Received 6 March 2011; received in revised form 24 June 2011; accepted 11 August 2011
Available online 15 September 2011

KEYWORDS
Anatomical regurgitation orifice;
Aortic paraprosthetic regurgitation;
Computed tomography;
Prosthetic heart valve

Summary
Background: Multi-detector computed tomography (MDCT) has been used to provide diagnostic information after heart valve replacements such as prosthetic valve dysfunction. However, only few data are available about aortic paraprosthetic regurgitation (APR). The aim of this study is to assess the feasibility, accuracy, and reproducibility of the existence of APR using contrast-enhanced 64-row MDCT.
Methods: We retrospectively evaluated 20 consecutive patients who underwent both 64-row MDCT and two-dimensional transthoracic echocardiography (2D-TTE) after aortic valve replacement. The presence of APR was evaluated with 64-row MDCT, and validated with 2D-TTE, two-dimensional transesophageal echocardiography (2D-TEE), or intraoperative findings if available. If APR was present, we also evaluated paraprosthetic anatomical regurgitation orifice (PARO) area to quantify the prognostic impact of APR or for surgical planning such as closure device sizing.
Results: Overall, 12 of 20 valves showed beam-hardening artifact (BHA) which made the reliable evaluation of APR difficult. The presence of artifact seemed to depend on valve types. Among 8 patients who did not show BHA, there were perfect agreements between MDCT and 2D-TTE, 2D-TEE, or intra-operative findings about APR. There were excellent inter-observer agreements in the evaluation of APR and PARO area. PARO area was consistent with the echocardiographic severity of APR in this study.

* Corresponding author at: Division of Cardiology, Osaka Rosai Hospital, 1179-3 Nagasone-cho, Kita-ku, Sakai, Osaka 591-8025, Japan. Tel.: +81 72 252 3561; fax: +81 72 250 5492.
E-mail address: wpgjq774@yahoo.co.jp (M. Hara).

doi:10.1016/j.jjcc.2011.08.002

Conclusions: Our retrospective data suggest that MDCT could be a reliable technique for the evaluation of APR after On-X standard or SJM standard valve replacement. MDCT can become a novel quantitative tool for the evaluation of PARO area.

Introduction

Aortic valve replacement is an effective and promising treatment in patients with significant aortic valvular heart diseases [1]. Aortic paraprosthetic regurgitation (APR) is one of the rare complications after aortic valve replacement, however, some patients require further surgical or transcatheter closure of APR because it could be life-threatening [2—5]. Two-dimensional echocardiography has long been used as an essential method for the assessment of these complications after heart valve replacement [3—7]. However, it is difficult to accurately evaluate the exact location of the paraprosthetic leaks and size of the defects using two-dimensional echocardiography partly due to mechanical or reverberation artifacts [3—7].

Recently, multi-detector computed tomography (MDCT) has been used to provide diagnostic information after heart valve replacements such as prosthetic valve dysfunction [8—11]. However, only case reports are available about APR detected by MDCT [8,9,12]. The aim of this study is to assess the feasibility, accuracy, and reproducibility of the existence of APR using contrast-enhanced 64-row MDCT, and compared to already standardized two-dimensional echocardiographic evaluation. We also measured the paraprosthetic anatomical regurgitation orifice (PARO) area to quantify the prognostic impact of APR or for surgical planning such as closure device sizing.

Methods

Study patients

We retrospectively enrolled 20 consecutive patients who underwent both 64-row MDCT and two-dimensional transthoracic echocardiography (2D-TTE) after aortic valve replacement between September 2007 and December 2009. Fifteen patients underwent mechanical valve replacement (6 On-X standard, On-X Life Technologies Inc., Austin, TX, USA; 2 SJM standard, 5 SJM HP, and 1 SJM Regent valves, St. Jude Medical Inc., St. Paul, MN, USA; 1 ATS, ATS Medical Inc., Minneapolis, MN, USA) and the remaining 5 patients underwent biological valve replacement (1 CEP and 4 Magna valves, Edwards Lifesciences, Irvine, CA, USA). Patients with suspected APR by 2D-TTE also underwent two-dimensional transesophageal echocardiography (2D-TEE) for additional evaluation of APR. This study includes one previously published case report of APR [12]. The mean time difference between MDCT and 2D-TTE was 39 ± 48 days, and patients who showed any changes in clinical status during the interval were excluded from the study. First, we evaluated the presence of beam-hardening artifact (BHA) which was defined as a black shining line projecting outward from the prosthetics because the artifact impairs visualization around the prosthetics and makes the precise evaluation of APR difficult (Fig. 1). Then, we evaluated the presence of APR and PARO area using 64-row MDCT among 8 of 20 prosthetics without BHA. The presence of APR was validated with 2D-TTE, 2D-TEE, or intraoperative findings if available (Table 1). Written informed consent was obtained from all patients before CT evaluation, and the institutional review board approved this study.

Echocardiographic evaluation

Two-dimensional echocardiography was performed using commercially available ultrasound system (Aplio, Toshiba Medical, Tokyo, Japan) by an experienced medical doctor and sonographer. The consensus-based findings were used for the analysis. The existence and severity of APR were assessed with Doppler echocardiography. We defined APR when the flow jet signal was identified outside of the prosthetic reverberations at diastole. The severity of APR was classified into 3 categories (mild, moderate, and severe) in a comprehensive manner using regurgitation jet area, vena contracta, regurgitation duration, and left ventricular size analyses [13].

Computed tomography acquisition

Data were acquired with a 64 multi-detector row dual source CT (SOMATOM Definition, Siemens Medical Systems, Munich, Germany) with a detector collimation width of 0.6 mm and a gantry rotation time of 0.33 s within a single breath hold. Tube voltage was fixed at 120 kV with tube current of 850 mA. Scan direction was craniocaudal. Electrocardiogram modulation was not used. The timing of data acquisition was determined with a bolus tracking method with a threshold of 150 Hounsfield Unit by setting region of interest to ascending aorta at the bifurcation level of pulmonary artery. Contrast enhancement was obtained using nonionic contrast medium injection (Iopamirone 370 mgI/dL, Bayer Health Care, Leverkusen, Germany) from antecubital venous approach with a 20-gauge cannula. Contrast medium was administered at a flow rate of 4 mL/s. A beta-blocker (40 mg of metoprorol) was given before the examination at attending physicians' discretion because bradycardia may worsen heart failure symptoms with aortic regurgitation. Images were reconstructed from 0 to 90% of the RR interval with 10% intervals for subsequent off-line analysis.

Evaluation of APR

Data analysis was performed off-line using commercially available workstation (AquariusNetStation, Terarecon Inc.,

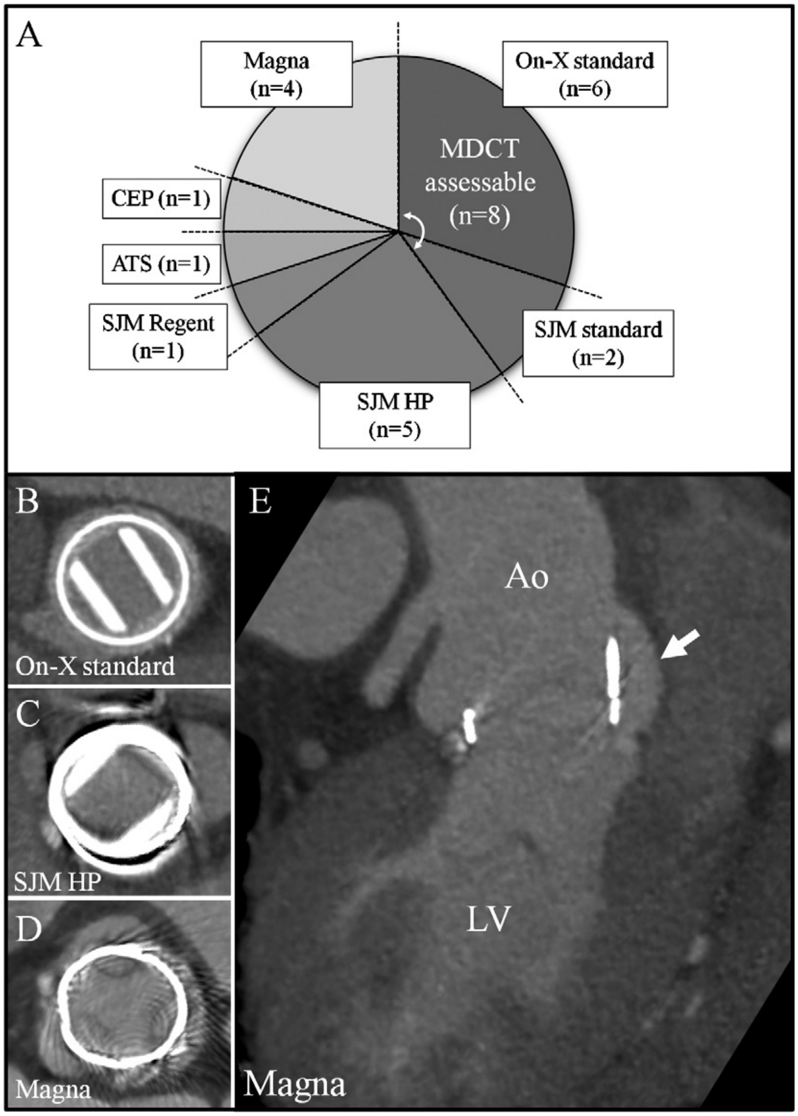

Figure 1 Relationship between valve type and presence of beam-hardening artifacts. Eight of twenty prosthetics could be evaluated for the presence of aortic paraprosthetic regurgitation (APR) by multi-detector computed tomography (MDCT) without beam-hardening artifacts (BHA) (A). On-X standard (B) or SJM standard valves were fully visualized without BHA. On the other hand, SJM HP (C), SJM Regent, and ATS valves showed significant artifacts which made the precise evaluation around prosthetics difficult. CEP or Magna valves (D) showed BHA around struts. However, possible APR was identified outside of the Magna valve (E, arrow). Ao, aorta; LV, left ventricle.

San Mateo, CA, USA). The reconstruction window was positioned at 90% of RR interval for the evaluation of APR and PARO area with convolution kernel of B45f. First, the short-axis view of the prosthetic aortic valve was obtained (Fig. 2). After identifying the center of the valve, we obtained long-axis views. The presence of APR was evaluated using long-axis view with 1 mm slice maximum intensity projection image by rotating it 360° with 1° intervals while maintaining the center of the valve. The bridge between aortic root and left ventricle outside of prosthetic valve was defined as the presence of APR. If APR was revealed, PARO area was measured by drawing central line. The smallest PARO area was used for the evaluation (Fig. 2). Window width and level were at the discretion of the readers.

Statistical analysis

Statistical analysis was performed using SPSS software (version 11, SPSS Inc., Chicago, IL, USA). Continuous variables are presented as mean ± SD. Discrete variables are presented as number (%). One fellowship-trained cardiologist and one experienced cardiologist who are in charge of MDCT evaluations at Osaka Rosai Hospital analyzed the data to determine reproducibility of the CT analysis. They were blinded to any clinical and echocardiographic information. Diagnostic accuracy and reproducibility such as sensitivity, specificity, and inter-observer agreements were not analyzed statistically because of small sample size and complete agreements between observers. Results are presented in Table 1.

Table 1 MDCT, 2D-E and operative findings after aortic valve replacement.

Case	Age	Sex	Prosthetics	APR MDCT	APR 2D-E	Re-ope	PARO1	PARO2	Duration (days)
1	73	Male	On-X standard	No	No	No	0	0	371
2	65	Male	On-X standard	No	No	No	0	0	28
3	69	Female	On-X standard	No	No	No	0	0	498
4	72	Male	On-X standard	No	No	No	0	0	20
5	36	Male	On-X standard	No	No	No	0	0	33
6	67	Male	On-X standard	No	No	No	0	0	231
7	61	Female	SJM standard	Yes	Severe	Yes	48.4	43.6	4551
8	56	Male	SJM standard	Yes	Severe	Yes	22.6	21.7	4938

Patients with suspected aortic paraprosthetic regurgitation (APR) by two-dimensional transthoracic echocardiography (2D-TTE) also underwent two-dimensional transesophageal echocardiography (2D-TEE) for additional evaluation of APR. The presence of APR was determined in a comprehensive way with 2D-TTE and 2D-TEE findings. 2D-E, 2D-TTE with or without 2D-TEE; duration, duration from aortic valve replacement; MDCT, multi-detector computed tomography; PARO, paraprosthetic anatomical regurgitation orifice area (mm^2); Re-ope, re-operation after MDCT.

Results

Fig. 1 shows the relationship between valve type and the presence of BHA. Eight of twenty prosthetics could be evaluated by MDCT without BHA. The presence of artifact seemed to depend on valve types. On-X standard or SJM standard valves were fully visualized without BHA. On the other hand, SJM HP, SJM Regent, and ATS valves showed significant artifacts which made the precise evaluation around prosthetics difficult. CEP or Magna valves showed BHA around struts (Fig. 1).

Eight prosthetics without BHA were then evaluated for the presence of APR, and results were compared with 2D-TTE, 2D-TEE, or intraoperative findings if available (Table 1). In these 8 patients, age was 62 ± 12 years old, 6 (75%) were male, body surface area was $1.7 \pm 0.1\,m^2$, estimated glomerular filtration rate was $81 \pm 19\,mL/min/1.73\,m^2$, contrast medium used for MDCT was $71 \pm 6\,mL$, heart rate during MDCT was 70 ± 18 bpm, left ventricular end-diastolic volume was $169 \pm 67\,mL$, end-systolic volume was $86 \pm 45\,mL$, and left ventricular ejection fraction was $49 \pm 14\%$. As shown in Table 1, there were perfect agreements between MDCT and two-dimensional echocardiographic findings about APR. Besides, intra-operative findings were also completely compatible with MDCT findings in cases 7 and 8 (Fig. 2). There were excellent inter-observer agreements between observer 1 and 2 about the evaluation of APR and PARO area.

Two patients with APR showed some causes of tissue fragility around the prosthetics. The patient of case 7 in Table 1 underwent aortic valve replacement because of severe aortic regurgitation due to aortitis, and the patient of case 8 in Table 1 underwent aortic and mitral valve replacement because of severe aortic and mitral regurgitation due to infectious endocarditis [12]. On the other hand, none of the remaining 6 patients in Table 1 showed any causes of tissue fragility at the day of valve replacement.

In addition, possible APR was identified outside of the Magna valve even with BHA around struts in one case (Fig. 1E). The presence of APR was validated with two-dimensional echocardiography, and the possible PARO area was $11.74\,mm^2$ by observer 1 and $10.41\,mm^2$ by observer 2 which is consistent with two-dimensional echocardiographic findings of moderate APR in this case.

Discussion

In this study, we newly proposed the methodology for the evaluation of APR by MDCT. We demonstrated that MDCT accurately identifies the existence of APR compared to 2D-TTE, 2D-TEE, or intra-operative findings if available. PARO area could be quantified with good reproducibility.

Artifact and valve type

We demonstrated that the presence of artifact seemed to depend on valve types (Fig. 1). On-X standard or SJM standard valves were fully visualized without BHA. On the other hand, SJM HP, SJM Regent, ATS, CEP, and Magna valves showed BHA which made the precise evaluation around prosthetics difficult. Tsai et al. reported that suture loosening could be evaluated using MDCT after one aortic valve replacement and 3 mitral valve replacements with On-X mechanical valves [9]. On the other hand, Chenot et al. reported that CEP shows BHA around metal struts [14]. These reports support our data. Even though SJM standard valve was assessable without BHA by MDCT, SJM HP or SJM Regent valves showed BHA. We speculated that newly equipped MP35N (Nickel—Cobalt—Chromium—Molybdenum) alloy in suturing cuff of SJM HP or Regent valves may affect the BHA. Thus, we think that architectural components rather than prosthetic valve design may cause BHA.

PARO area by MDCT

We evaluated PARO area to quantify the prognostic impact of APR, and revealed that PARO area assessed by MDCT was consistent with the echocardiographic severity of APR in this study.

Conventionally, effective regurgitation orifice area (EROA) has been applied for the quantitative assessment of native aortic valvular regurgitation in addition to the qualitative assessment such as regurgitation jet area or vena contracta [13]. EROA < $10\,mm^2$ is considered as mild, EROA of 10—$20\,mm^2$ as mild to moderate, EROA of 20—$30\,mm^2$ as moderate to severe, and EROA > $30\,mm^2$ as severe aortic regurgitation [13]. However, quantitative two-dimensional

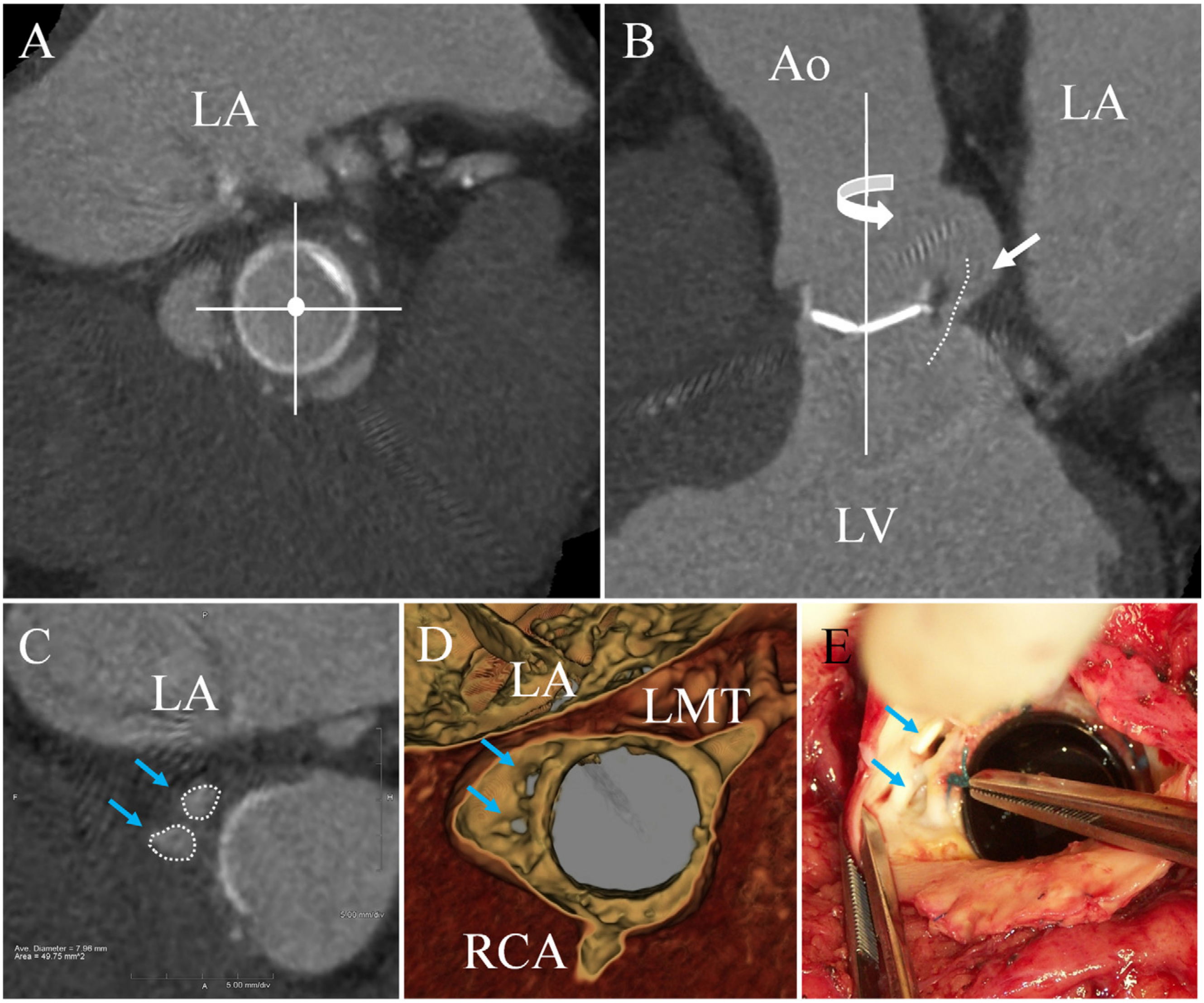

Figure 2 Evaluation of aortic paraprosthetic regurgitation (APR). A 56-year-old male with SJM standard valve was evaluated (case 8 in Table 1). First, short-axis view of the prosthetic aortic valve was obtained (A). After identifying the center of the valve, we obtained long-axis views. The presence of APR was evaluated using long-axis view with 1 mm slice maximum intensity projection image by rotating it 360° with 1° intervals while maintaining the center of the valve (B). The bridge between aortic root and left ventricle outside of prosthetic valve was defined as the presence of APR (B, arrow). If APR was revealed, paraprosthetic anatomical regurgitation orifice (PARO) area was measured by drawing central line (B, dotted line). The smallest PARO area was used for the evaluation (C). Volume-rendering image of APR viewed from ascending aorta was reconstructed (D). The multi-detector computed tomography findings were completely compatible with operative findings (E). Lower PARO was distorted in order to enlarge the viewing field by tweezers and association between aorta and left ventricle could not be visualized well. Arrows indicate the presence of APR. Ao, aorta; LA, left atrium; LMT, left main trunk; LV, left ventricle; RCA, right coronary artery.

echocardiographic assessment of APR is difficult because reverberation artifact makes it difficult to analyze flow convergence [13]. 3D-TTE has the potential to evaluate the presence of APR but its resolution is not sufficient so far [6,7]. Because the minimum spatial resolution of this MDCT is 0.33 mm according to the manufacturer specifications, we considered that it is possible to assess APR severity using PARO area which may require at least 1 mm^2 spatial resolution referred to the EROA classification of aortic regurgitation by 2D-TTE [13]. Patients with severe APR (case 7 in Table 1) and moderate to severe APR (case 8 in Table 1) by MDCT needed surgical treatment in order to manage New York Heart Association class 3 heart failure symptoms. In addition, possible mild to moderate APR with BHA (Fig. 1E) has been followed-up carefully for 7 months medically without any worsening and operation. Even though we should remember that BHA around struts may obscure the presence of additional APR in the case of Fig. 1, this case implies that the presence of APR could be evaluated in some cases with BHA. Although the sample size is very small, clinical outcomes shown in this study are consistent with APR severity classification by MDCT. Thus, we think the PARO area assessed by MDCT might be accurate [15], and is applicable for assessing prognostic impact of APR and for surgical planning such as closure device sizing.

Clinical implications

Our data suggest that MDCT is a reliable technique for the evaluation of APR and PARO area after aortic valve replacements with On-X standard or SJM standard valves. Thus, we believe that MDCT should be applied for additional evaluation and surgical planning in conjunction with echocardiography if APR is suspected after On-X standard or SJM standard valve replacement. Next-generation MDCT-assessable prosthetic valves should develop, especially for patients who showed inflammatory diseases which may lead to tissue fragility around the prosthetics.

Study limitations

Our study has several limitations. First, it was a single center retrospective study which has small sample size partly because APR is uncommon. Second, we enrolled consecutive CT examinations, but not consecutive patients with aortic valve replacement. It may lead to a biased result. Finally, 2D-TTE was used as a gold standard in this study. It has some limitations in the evaluation of prosthetic valves although we also used 2D-TEE or operative findings if available [6,7,13].

Conclusions

Our retrospective data suggest that MDCT could be a reliable technique for the evaluation of APR and PARO area after On-X standard or SJM standard valve replacement. Further large scale prospective study is needed to confirm our conclusion.

References

[1] Bonow RO, Carabello BA, Chatterjee K, de Leon AC Jr, Faxon DP, Freed MD, Gaasch WH, Lytle BW, Nishimura RA, O'Gara PT, O'Rourke RA, Otto CM, Shah PM, Shanewise JS. 2006 Writing Committee Members, et al. 2008 Focused update incorporated into the ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Revise the 1998 Guidelines for the Management of Patients With Valvular Heart Disease): endorsed by the Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons. Circulation 2008;118:e523—661.

[2] Hammermeister KE, Sethi GK, Henderson WG, Oprian C, Kim T, Rahimtoola S. A comparison of outcomes in men 11 years after heart-valve replacement with a mechanical valve or bioprosthesis. Veterans Affairs Cooperative Study on Valvular Heart Disease. N Engl J Med 1993;328:1289—96.

[3] Rallidis LS, Moyssakis IE, Ikonomidis I, Nihoyannopoulos P. Natural history of early aortic paraprosthetic regurgitation: a five-year follow-up. Am Heart J 1999;138:351—7.

[4] O'Rourke DJ, Palac RT, Malenka DJ, Marrin CA, Arbuckle BE, Plehn JF. Outcome of mild periprosthetic regurgitation detected by intraoperative transesophageal echocardiography. J Am Coll Cardiol 2001;38:163—6.

[5] Latson LA. Transcatheter closure of paraprosthetic valve leaks after surgical mitral and aortic valve replacements. Expert Rev Cardiovasc Ther 2009;7:507—14.

[6] Singh P, Inamdar V, Hage FG, Kodali V, Karakus G, Suwanjutah T, Hsiung MC, Nanda NC. Usefulness of live/real time three-dimensional transthoracic echocardiography in evaluation of prosthetic valve function. Echocardiography 2009;26:1236—49.

[7] Shiota T. 3D echocardiography: the present and the future. J Cardiol 2008;52:169—85.

[8] Konen E, Goitein O, Feinberg MS, Eshet Y, Raanani E, Rimon U, Di-Segni E. The role of ECG-gated MDCT in the evaluation of aortic and mitral mechanical valves: initial experience. Am J Roentgenol 2008;191:26—31.

[9] Tsai IC, Lin YK, Chang Y, Fu YC, Wang CC, Hsieh SR, Wei HJ, Tsai HW, Jan SL, Wang KY, Chen MC, Chen CC. Correctness of multi-detector-row computed tomography for diagnosing mechanical prosthetic heart valve disorders using operative findings as a gold standard. Eur Radiol 2009;19:857—67.

[10] LaBounty TM, Agarwal PP, Chughtai A, Kazerooni EA, Wizauer E, Bach DS. Hemodynamic and functional assessment of mechanical aortic valves using combined echocardiography and multidetector computed tomography. J Cardiovasc Comput Tomogr 2009;3:161—7.

[11] LaBounty TM, Agarwal PP, Chughtai A, Bach DS, Wizauer E, Kazerooni EA. Evaluation of mechanical heart valve size and function with ECG-gated 64-MDCT. Am J Roentgenol 2009;193:W389—96.

[12] Toda K, Taniguchi K. Periprosthetic leakage identified by multi-slice computed tomography. Ann Thorac Surg 2010;89:310.

[13] Zoghbi WA, Enriquez-Sarano M, Foster E, Grayburn PA, Kraft CD, Levine RA, Nihoyannopoulos P, Otto CM, Quinones MA, Rakowski H, Stewart WJ, Waggoner A, Weissman NJ, American Society of Echocardiography. Recommendations for evaluation of the severity of native valvular regurgitation with two-dimensional and Doppler echocardiography. J Am Soc Echocardiogr 2003;16:777—802.

[14] Chenot F, Montant P, Goffinet C, Pasquet A, Vancraeynest D, Coche E, Vanoverschelde JL, Gerber BL. Evaluation of anatomic valve opening and leaflet morphology in aortic valve bioprosthesis by using multidetector CT: comparison with transthoracic echocardiography. Radiology 2010;255:377—85.

[15] Vural M, Ucar O, Celebi OO, Cicekcioglu H, Durmaz HA, Selvi NA, Koparal S, Aydogdu S. Evaluation of effective regurgitant orifice area of mitral valvular regurgitation by multislice cardiac computed tomography. J Cardiol 2010;56:236—9.